California Air Resources Board

Quantification Methodology for the California Department of Food and Agriculture Dairy Digester Research and Development Program

Greenhouse Gas Reduction Fund Fiscal Year 2017-18

December 15, 2017

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Section A. Introduction

The goal of California Climate Investments (CCI) is to reduce greenhouse gas (GHG) emissions and further the purposes of the Global Warming Solutions Act of 2006, known as Assembly Bill (AB) 32. The California Air Resources Board (CARB or Board) is responsible for providing the quantification methodology to estimate the net GHG benefit and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). CARB develops these methodologies based on the project types eligible for funding by each administering agency as reflected in the program Expenditure Records available at: https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/expenditurerecords.htm. CARB staff periodically reviews each quantification methodology to evaluate its effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified.

For the California Department of Food and Agriculture's (CDFA) Dairy Digester Research and Development Program (DDRDP), CARB staff developed this Quantification Methodology and associated DDRDP Calculator Tool to provide methods for estimating net GHG benefit of each proposed project (Section B), provide instructions for documenting and supporting the estimate (Section C), and outline the process for tracking and reporting GHG and other benefits once a project is funded (Section D).

This methodology uses the DDRDP Calculator Tool to estimate GHG emission reductions to be achieved through the installation of a biogas control system (BCS), commonly referred to as a dairy digester, which captures and utilizes biogas produced by the anaerobic decomposition of livestock manure and/or other organic material. Projects will report the total project GHG emission reductions over the project life estimated using this methodology, the total project GHG emission reductions per unit of energy-corrected milk production, and the total project GHG emission reductions per dollar of GGRF funds requested.

In an effort to enhance the analysis, provide greater transparency, and assist in project-level reporting, CARB also included an additional output tab in the DDRDP Calculator Tool that summarizes key variables from DDRDP projects. Key variables estimated include: fossil fuel use reductions (onsite) in diesel gallons equivalent, renewable fuel generation in diesel gallons equivalent, and renewable electricity generation in kWh. CARB continues to develop methodologies to assess additional social, economic, and environmental co-benefits achieved by CCI.

DDRDP Project Types

The CDFA DDRDP reduces GHG emissions through the installation of a biogas control system (BCS), which captures and utilizes biogas produced by the anaerobic decomposition of livestock manure and/or other organic material. CDFA identified several project types that meet the objectives of the DDRDP and for which there are methods to quantify GHG emission reductions.[i] Each DDRDP project requesting GGRF funding must include at least one of the following project components for FY 2017-18:

- BCS that utilizes recovered biogas for electricity generation;
- BCS that recovers biogas and upgrades to biomethane for use as transportation fuel, whether onsite, at a nearby facility, or through pipeline injection;
- BCS that recovers biogas for combustion in a boiler that utilizes thermal energy in a process thereby reducing demand for fossil-fuel based energy in that process.

Manure management projects that do not include the installation of a BCS may be eligible for funding under the Alternative Manure Management Practices Program (AMMP) also administered by CDFA.

Section B provides the methods to use based on the project component(s) proposed.

Methodology Development

CARB and CDFA developed this Quantification Methodology through a public process consistent with the guiding implementation principles of California Climate Investments, including ensuring transparency and accountability.[ii] This Quantification Methodology was developed to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology will:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven tools and methods;
- Use project-level data, where available and appropriate; and
- Result in GHG emission reduction estimates that are conservative and supported by empirical literature.

CARB, in consultation with CDFA, reviewed peer-reviewed literature and tools and consulted with experts as needed to determine methods appropriate for the DDRDP project types. The methods were developed to provide reliable estimates with data readily available to project proponents.

This Quantification Methodology is based on CARB's 2014 Compliance Offset Protocol for Livestock Projects (Livestock Protocol).[iii] The Livestock Protocol was initially adopted by the Board on October 20, 2011 for the purpose of ensuring the complete, consistent, transparent, accurate, and conservative quantification of the net GHG benefit associated with a livestock digester offset project in order to generate CARB offset credits for use in the Cap-and-Trade Program.[iv] An updated version of the Livestock Protocol was adopted by the Board on November 14, 2014.

While the Livestock Protocol is used to generate CARB offset credits based on measured data after implementation of a project, this Quantification Methodology is used to estimate the net GHG benefit of a project prior to project implementation in order to assist in awarding competitive GGRF grants. For this reason, this Quantification Methodology includes some simplifying assumptions due to the need to estimate emission reductions prior to implementation of a BCS project.

CARB developed the initial FY 2014-15 DDRDP Quantification Methodology[v] based on a calculation of pre-project baseline GHG emissions, which represents the maximum potential GHG reductions that a BCS project may achieve. The Quantification Methodology was updated in FY 2016-17 to include an estimation of post-project emissions as well as an estimation of the GHG benefits of utilizing recovered biogas to displace fossil fuel use. The FY 2017-18 version incorporates methods to quantify several key variables in addition to GHG calculations.

CARB released the Draft DDRDP Quantification Methodology and Draft DDRDP Calculator Tool for public comment in November 2017. This Final DDRDP Quantification Methodology and accompanying DDRDP Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the DDRDP Program Guidelines.

Tools

Applicants must use this Quantification Methodology, in conjunction with the accompanying DDRDP Calculator Tool, to estimate the net GHG emission reductions of the proposed project. The DDRDP Calculator Tool can be downloaded from: www.arb.ca.gov/cci-quantification. Required inputs to the DDRDP Calculator Tool are listed in Section B, Step 2. Instructions to use the tool are provided in Section B and an example project is included in Appendix A.

In addition, this Quantification Methodology also relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in quantification methodologies, referred to as the CCI Quantification Methodology Emission Factor Database (Database).[vi] The Database Documentation explains how emission factors used in CARB quantification methodologies are developed and updated.

Updates

CARB staff periodically review each Quantification Methodology to evaluate its effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated this Quantification Methodology from the previous version[vii] for FY 2017-18 to incorporate changes in reporting requirements (Section D) consistent with the most recent Funding Guideline,[viii] and to include methodologies to quantify additional key variable associated with

DDRDP projects. These key variables, displayed in a new “Co-benefit Summary” output tab in the Calculator Tool, include:

- Fossil Fuel Use Reductions (onsite reductions) over 10 years (gallons)
- Renewable Fuel Generation over 10 years (gallons)
- Renewable Energy Generation over 10 years (kWh)

In addition, the option for applicants to use several non-default values in the DDRDP Calculator Tool has been removed to provide for greater consistency among applications and to simplify the application and project review process.

Program Assistance

CDFA staff, along with the Technical Advisory Committee (TAC) – a sub-committee of the California-Federal Dairy Digester Working Group – and other technical experts as needed, will review the quantification portions of the DDRDP project applications to ensure that the methods described in this document have been properly applied to estimate the GHG emission reductions for a proposed project. Applicants should use the following resources for additional questions and comments:

- Questions on this document should be sent to GGRFProgram@arb.ca.gov.
- For more information on CARB’s efforts to support implementation of GGRF investments, see: https://www.arb.ca.gov/auctionproceeds.
- Questions pertaining to the DDRDP should be sent to cdfa.oefi@cdfa.ca.gov.

Section B. Quantification Methodology

Overview

This methodology estimates the net GHG benefit of a proposed DDRDP project based on avoided methane emissions from anaerobic manure decomposition. It also includes an estimation of the benefit for avoided CO_2 emissions associated with electricity generation in projects where biogas will be used to generate electricity; with diesel fuel in projects where biogas is upgraded to biomethane for use as transportation fuel; and with fossil natural gas in projects where thermal energy from biogas is combusted in a boiler for useful thermal energy.

Methane production depends on the amount of manure produced, the fraction of volatile solids that decompose anaerobically (i.e., the biodegradable organic material in the manure), temperature, and the retention time of manure during treatment and storage. This methodology combines project-specific data with default factors to establish both a baseline scenario and a project scenario.

Net GHG emission reductions are calculated by subtracting estimated post-project GHG emissions from the uncontrolled baseline scenario emissions. Additional GHG emissions reductions are then added based on the end use of the captured biogas.

In general, the net GHG emission reductions are calculated using the following approaches:

Table 1. General Approach to GHG Quantification

BCS with electricity generation
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of electricity generation)
BCS with upgrade to biomethane for use as transportation fuel (either onsite or through pipeline injection)
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of production of biomethane)
BCS with recovery of useful thermal energy from combustion of biogas in boiler
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of recovered thermal energy)

Methods and equations used in the DDRDP Calculator Tool for estimating the net GHG emission reductions are provided in Appendix B. Emission factors used in calculations are contained in the Database available at: www.arb.ca.gov/cci-quantification. Documentation on the sources and methods used to develop the emission factors are also provided.

Applicants will follow the steps outlined in Figure 1 to estimate the net GHG emission reductions from the proposed project. Detailed instructions for each step are provided on subsequent pages. An example project showing how to estimate the net GHG emission reductions from a DDRDP project is included in Appendix A.

Figure 1. Steps to Estimate Net GHG Emission Reductions

Step 1. Identify the Project Boundary

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Step 2. Determine the DDRDP GHG Calculator Tool Inputs Needed

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Step 3. Locate and Report the Net GHG Emission Reductions and Co-benefits using the DDRDP GHG Calculator Tool

Step 1: Identify the Project Boundary

The project boundary delineates the GHG sources, sinks, and reservoirs (SSRs) that are included or excluded when quantifying the emission reductions resulting from the installation and operation of devices associated with the capture and destruction of methane. The calculation procedure only incorporates methane and carbon dioxide; nitrous oxide emissions are not assessed.[1]

Table 2 lists the SSRs for DDRDP projects, indicating which gases are included or excluded from the project boundary for the purpose of this methodology.

[1] The IPCC notes that the nitrification of ammonia to nitrate is an essential prerequisite to the emission of N_2O from animal manures, and this process does not occur under anaerobic conditions. As a result, they assign an N_2O emission factor of 0 for direct N_2O emissions from both anaerobic lagoons and anaerobic digesters. Thus diverting manure from one anaerobic environment (lagoon) to another (BCS) is unlikely to significantly alter the N_2O profile of a dairy's manure management operations. *IPCC Guidelines for National Greenhouse Gas Inventories* (2006). Volume 4: Agriculture, Forestry and Other Land Use: Chapter 10: Emissions from Livestock and Manure Management. (10.52,10.62-10.63). http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf.

Table 2. Description of all SSRs

SSR	GHG Source	CO_2	CH_4
1	Emissions from enteric fermentation	Excluded	Excluded
2	Emissions from mobile and stationary support equipment*	Included	Excluded
3	Emissions from mechanical systems used to collect and transport waste (e.g., engines and pumps for flush systems; vacuums and tractors for scrape systems)*	Included	Excluded
4	Vehicle emissions (e.g., for centralized digesters)*	Included	Excluded
5	Emissions from waste treatment and storage including: anaerobic lagoons, dry lot deposits, compost piles, solid storage piles, manure settling basins, aerobic treatment, storage ponds, etc.	Excluded	Included
6	Emissions from support equipment*	Included	Excluded
7	Emissions from the anaerobic digester due to biogas collection inefficiencies and venting events	Excluded	Included
8	Emissions from the effluent pond	Excluded	Included
9	Vehicle emissions for land application and/or off-site transport*	Included	Excluded
10	Emissions from combustion during flaring, including emissions from incomplete combustion of biogas	Excluded	Included
11	Emissions from combustion during electric generation, including incomplete combustion of biogas	Excluded	Included
12	Emissions from equipment upgrading biogas for pipeline injection or use as transportation fuel*	Included	Excluded
13	Emissions from combustion of biogas at boiler including emissions from incomplete combustion	Excluded	Included
14	Emissions or emission reductions from combustion of biogas by end user of pipeline biomethane or biomethane transportation fuel	**Included	Included
15	Emission reductions associated with delivery and use of project electricity to grid	***Included	Excluded
16	Off-site thermal energy or power	Excluded	Excluded
17	Use of project-generated thermal energy	****Included	Excluded
18	Project construction and decommissioning emissions	Excluded	Excluded

* Carbon dioxide emissions associated with the baseline or project scenario include, but are not limited to, the following sources: electricity use by pumps and equipment, fossil fuel generators used to destroy biogas; power pumping systems; milking parlor equipment; flares; tractors that operate in barns or freestalls; on-site manure hauling trucks; and vehicles that transport manure off-site.

** When biogas is upgraded to biomethane and used as transportation fuel onsite or through pipeline injection, the benefit of avoided diesel CO_2 emissions is calculated.

*** When a BCS uses biogas to generate electricity, a benefit associated with avoided fossil CO_2 emissions is also calculated based on a California grid-average emission factor.

**** When biogas is combusted in a boiler and recovered thermal energy is utilized in a non-BCS related process that reduces the demand for fossil-based energy, the benefit of avoided fossil natural gas CO_2 emissions is calculated.

Step 2: Determine the DDRDP Calculator Tool Inputs Needed

Table 3 identifies the required data inputs needed to estimate the net GHG emission reductions for proposed projects with the DDRDP Calculator Tool.

Table 3. Required DDRDP Calculator Tool Inputs

General Information (Read Me worksheet) • Project Name; • Grant Application Pin #; • Contact Name; • Contact Phone Number; • Contact Email; and • Date Completed. **Project Information** • Type of BCS (i.e. covered lagoon, plug flow, complete mix or fixed film); • Primary biogas destruction device or end use (from drop-down list); • Secondary biogas destruction device or end use (if applicable); • Fraction of biogas to be destroyed in each destruction device over 10 years; • Type of solid-separation both before and after installation of the BCS (e.g., stationary screen, screw press, etc.) selected from a drop-down list; • Presence of any uncovered effluent pond after installation of BCS; • Project location (County); • GGRF funds requested; • Specifications of milk produced (lbs/day, % fat, % true protein,% lactose); • Number of livestock by category (dairy cows in freestalls, dairy cows in open lot corrals, dry cows, and heifers) based on average of preceding 12 months data; • % of volatile solids separated prior to entry into the anaerobic lagoon or BCS, and sent to another treatment/storage practice, and identification of that practice from a drop-down list for each livestock category (baseline and project scenario); • % of volatile solids sent to the anaerobic treatment/storage system in the baseline and sent to the BCS after installation; • Baseline electricity and fossil fuel consumption associated with manure management activities by fuel type (MWh/yr, gallons/yr, scf/yr, or MMBtu/yr); • Estimated electricity and fossil fuel consumption associated with manure management activities by fuel type (MWh/yr, gallons/yr, scf/yr, or MMBtu/yr) after installation of the BCS; and • Descriptive list of stationary and mobile CO_2 emission sources associated with manure management activities.

Step 3: Estimate Net GHG Emission Reductions and Co-benefits for the Proposed Project Using the DDRDP Calculator Tool

Applicants must use the DDRDP Calculator Tool to complete this step. The Calculator Tool can be downloaded from www.arb.ca.gov/cci-quantification.

Users should begin with the **Read Me** tab, which contains instructions and prompts users to enter project information. Key terms are defined in the **Definitions** tab. The **Project Data Inputs** tab identifies inputs required by the user. Input and output fields are color coded:

- **Yellow** fields indicate that a direct user input is required, or that a selection from a drop-down box is required.
- **Green** fields indicate that a direct user input is optional, as it will be applicable for some projects but not others. All applicants should review these fields to determine the applicability to their project.
- **Gray** fields indicate fields that are automatically populated based on user entries, default values and/or the calculation methods.

The DDRDP Calculator Tool assists applicants in accounting for manure volatile solids in a step-by-step manner in both the baseline and project scenario. Where default values are provided in the DDRDP Calculator Tool, applicants must use these default values.

Input Proposed Project Information			
1. Biogas Control System (BCS)			
2a. Primary Biogas Destruction Device	Covered Lagoon Complete mix, plug flow, or fixed film digester		2b. % Biogas destroyed in primary destruction device (over 10 yrs)
2c. Secondary Biogas Destruction Device			2d. % Biogas destroyed in secondary destruction device (over 10 yrs)
3a. Baseline Solid Separation			
3b. BCS Solid Separation			
4. Uncovered Effluent Pond?*			
5. Project Location (county)			
6a. DDRDP GGRF $ Requested			
6b. Total GGRF $ Requested			
7a. Milk Fat (%)			
7b. Milk true Protein (%)			
7c. Milk Lactose (%)			
7d. Milk Produced (lbs/cow/day)			
ECM (kg/cow/day)	0.00		
10 yr ECM (mt)	0		

- **Input 1**: Applicants select the type of biogas control system ("covered lagoon" or "complete mix, plug flow or fixed-film digester design") from a drop down list.
- **Inputs 2a-2b**: Applicants identify the primary biogas destruction device (e.g., lean burn internal combustion engine, microturbine, boiler, upgrade and use of

gas as renewable CNG/LNG fuel), and the percent biogas expected to be destroyed in this device over 10 years.

- **Inputs 2c-2d**: If applicable, applicants may identify a secondary biogas destruction device and the associated percent biogas expected to be destroyed in this device over 10 years. This applies to projects that have both a primary and a secondary biogas destruction device or end use. For example, a project that upgrades biogas to biomethane transportation fuel may also still utilize an engine for electricity generation onsite. In such cases, the project applicant will indicate both the primary and secondary destruction device/pathway in the tool, and estimate the time-averaged percent of biogas to be destroyed in each pathway over 10 years.
  Note: Selection of multiple biogas destruction devices or pathways in the tool must be consistent with all project design documentation. A project must not claim GHG benefits related to upgrading to biomethane for transportation fuel if this remains an aspirational goal at the time of project application; such a claim must be supported by all project planning documentation and concrete steps taken by project applicants.
- **Input 3a**: Applicants identify existing solid separation technology, if any, for the flush system.
- **Input 3b**: Applicants identify solid separation technology, if any, that will be employed for a flush system after implementation of the DDRDP project.
- **Input 4**: Applicants indicate whether or not there will remain an uncovered effluent pond after implementation of the DDRDP project.
- **Input 5**: Applicants select the project location (county) from a drop-down list.
- **Input 6a**: Applicants enter the DDRDP GGRF Funds Requested ($) for all project features. This amount is equal to the amount of GGRF dollars the applicant is requesting from CDFA's DDRDP program.
- **Input 6b**: Applicants enter the Total GGRF Funds Requested ($) for all project features. This amount is equal to the amount of GGRF dollars the applicant is requesting from DDRDP, plus all GGRF dollars from CDFA or other agencies that have previously been awarded to the same project and any GGRF dollars from agencies other than CDFA that the project has or plans to apply for. If no other GGRF funds are requested, this will be the same amount as the DDRDP GGRF Funds Requested in input 6a.
- **Inputs 7a-7d**: Applicants input characteristics of milk produced by the dairy. This includes the average percent fat, true protein and lactose of the produced milk, as well as average daily production per cow (lbs milk per cow per day).

Applicants next follow a step-by-step process to describe baseline scenario (i.e. current practice) manure management.

	Baseline Manure Management -- Enter data regarding management practices using averages of preceding 12 months					
	8. Enter number of livestock by category	9a. Percent of manure volatile solids (VS) deposited on land and not entering wet/anaerobic environment	9b. Percent of VS from solid separation prior to wet/anaerobic environment and sent to other treatment/storage practice	9c. (if applicable) Enter % VS sent to any other non-anaerobic treatment/storage	9d. Enter % VS entering wet/anaerobic system (e.g., lagoon, storage pond) by livestock category	Total Volatile Solids must sum to 100%
Dairy Cows (freestall)	2,000	20%	13.6%		66.4%	100%
Dairy Cows (open lot corrals)		70%	5.1%			
Dry cows		70%	5.1%			
Heifers		70%	5.1%			
		Pasture / Dirt	solid storage			
			Identify current practice for separated solids	Identify other current treatment/storage practice		

Energy Use Associated with Current Waste Management Practices		
10. Electricity Consumed	MWh/yr	300
11a. Fuel Consumed	Diesel (Distillate No. 1 or 2, gal.)	500
11b. Fuel Consumed		
11c. Fuel Consumed		
	*Select Applicable Fuel(s) from List.	

- **Input 8**: Applicants enter the number of livestock by category based on the average of preceding 12 months data. These values are assumed to remain constant in both the baseline and project scenario.
- **Default Input 9a**: This is a fixed default value for the percent of manure volatile solids deposited directly on land and not entering a wet/anaerobic system. This Quantification Methodology assumes default values of 20% for dairy cows housed in freestalls, and 70% for dairy cows housed in open-lot corrals, as well as for dry cows and heifers.[2]
- **Default Input 9b**: This is a fixed default value for the percent of manure volatile solids that are separated out prior to entry into a wet/anaerobic system such as a lagoon (baseline scenario). Default values (adjusted to account for input 9a) are provided in the tool based on the solid separation technology, if any, identified by the applicant. Applicants also identify from a drop-down list how the separated solids will be treated or managed.
- **Input 9c**: This optional input allows applicants to account for any other manure volatile solids that do not enter a wet/anaerobic system (baseline scenario). For example, if there is more than one solid separation process in sequence at the dairy, or if some manure is scraped rather than flushed. The applicant will estimate the % of manure volatile solids and identify the appropriate treatment or storage practice.
- **Input 9d**: Applicants next enter the % of manure volatile solids that enter the anaerobic lagoon (baseline). This should be equal to 100% minus the sum of the values entered in inputs 9a-9c. If not, a warning notice will appear in the tool.
- **Inputs 10 – 11c**: Applicants enter electricity and fossil fuel consumption by fuel type for the baseline scenario based on energy consumption for manure management activities over the preceding 12 months. Fuel types are selected from drop down lists. Energy inputs are aggregated by fuel type, but applicants must also list combustion sources individually at the bottom of the worksheet (input 15).

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[2] These were derived from the average time cows spend inside and outside of areas where manure solids may be collected/flushed, and are based on the median values of the ranges given in the UC Davis Division of Agriculture and Natural Resources Committee of Experts on Dairy Manure Management (2005) study *Managing Dairy Manure in the Central Valley of California*. (23-24). http://groundwater.ucdavis.edu/files/136450.pdf.

Applicants will next repeat this process for the project scenario, describing how manure will be managed after the installation of a biogas control system (see below).

Project Manure Management -- Estimate Data Regarding Management Practices after Installation of BCS

	Number of Livestock by Category	12a. Percent of manure volatile solids (VS) deposited on land and not entering wet/anaerobic environment	12b. Percent of VS from solid separation prior to BCS sent to other treatment/storage practice	12c. (if applicable) Enter % VS sent to any other non-anaerobic treatment/storage	12d. Enter % VS sent to (managed in) biogas control system by livestock category	Total Volatile Solids must sum to 100%
Dairy Cows (freestall)	2,000	20%	13.6%		66.4%	100%
Dairy Cows (open lot corrals)	0	70%	5.1%			
Dry Cows	0	70%	5.1%			
Heifers	0	70%	5.1%			
		Pasture / Dirt	solid storage			
			Identify Post-Project Practice for Separated Solids	Identify Other Post-Project Practice		

Projected Energy Usage after Installation of Biogas Control System

13. Electricity Consumed	MWh/yr	100
14a. Fuel Consumed	Diesel (Distillate No. 1 or 2, gal.)	500
14b. Fuel Consumed	Natural Gas (MMBtu)	400
14c. Fuel Consumed	Propane / LPG (gallons)	30

*Select Applicable Fuel(s) from List.

15. Description of Stationary and Mobile Sources associated with Manure Management Activities included in GHG Emission Calculations

Source Description	Fuel Type	Change in emissions relative to Baseline
Manure collection equipment (e.g., trucks, tractors)	Diesel (Distillate No. 1 or 2, gal.)	No change
Supplemental fuel for engine	Natural Gas (MMBtu)	New source
Pilot light in engine	Propane / LPG (gallons)	New source

- **Default Input 12a**: This is fixed default for the percent of manure volatile solids expected to be deposited directly on land and not entering a wet/anaerobic environment after implementation of the DDRDP project.
- **Default Input 12b**: This is fixed default for the percent of manure volatile solids that will separated out prior to entry into the BCS (project scenario). Default values (adjusted to account for input 12a) are provided in the tool based on the solid separation technology, if any, identified by the applicant. Applicants also identify from a drop-down list how the separated solids will be treated or managed.
- **Input 12c**: Similar to input 9c, this optional input allows applicants to account for any other manure volatile solids that do not enter the BCS (project scenario).
- **Input 12d**: Applicants enter the percent of manure volatile solids that enter the BCS (project scenario). This should be equal to 100% minus the sum of the values entered in inputs 12a-12c. If not, a warning notice will appear in the tool.
- **Inputs 13 – 14c**: Applicants enter estimated electricity and fossil fuel consumption by fuel type for the project scenario based on proposed project design. Fuel types are selected from drop down lists. Energy inputs are aggregated by fuel type, but applicants must also list combustion sources individually at the bottom of the worksheet (input 15).
  Note: Projects that include electricity generation from biogas must still input estimated electricity consumption associated with manure management and the operation of the BCS, and *not* enter zero. GHG benefits associated with electricity generation are calculated separately in the DDRDP Calculator Tool.
- **Input 15**: Applicants list individual combustion sources and identify whether each is a new source, or whether GHG emissions from an existing source are expected to increase, decrease or remain unchanged as a result of the proposed DDRDP project. Input 15 is not used directly in GHG calculations, but is required supplementary information.

A detailed example of how to input project application data into the DDRDP Calculator tool is contained in Appendix A. Details of calculation methods are provided in Appendix B.

The **GHG Summary** tab displays GHG emission reduction metrics as described below.

- **Total Project GHG Emission Reductions** is equal to the difference between annual baseline and project emissions, plus any applicable additional GHG benefit from biogas end use, summed over the 10 year project life.
- **Total Project GHG Emission Reductions per kg of energy-corrected milk production** is calculated as:

  $$\frac{Total\ Project\ GHG\ Emission\ Reductions\ in\ Metric\ Tons\ of\ CO_2e}{Energy\ Corrected\ Milk\ Production\ (ECM)\ over\ 10\ years\ in\ metric\ tons}$$

  Note: This metric is intended to be used by CDFA in the application review and scoring process. Milk production characteristics from the **Project Data Inputs** tab are used to calculate energy-corrected milk. Using an energy-corrected milk production metric helps to account for differences in milk production rates and cow breeds among dairies.

- **Total Project GHG Emission Reductions per Dollar of Total GGRF funds requested** is calculated as:

  $$\frac{Total\ Project\ GHG\ Emission\ Reductions\ in\ Metric\ Tons\ of\ CO_2e}{Total\ GGRF\ Funds\ Requested\ (\$)}$$

  Note: If the project does not receive or request GGRF $ from any other California Climate Investments program, then the Total Project GHG Emission Reductions per Dollar of DDRDP GGRF funds will be equal to the Total Project GHG Emission Reductions per Dollar of Total GGRF funds requested.

- **Portion of total GHG emission reductions attributable to the DDRDP funding** ($MTCO_2e$);

  Note: If the project receives or requests GGRF $ from any other California Climate Investments program, the total GHG emission reductions are prorated among the programs based on the fraction of total GGRF funds requested.

- **Total Project GHG Emission Reductions per Dollar of DDRDP GGRF funds requested** is calculated as:

  $$\frac{Total\ Project\ GHG\ Emission\ Reductions\ in\ Metric\ Tons\ of\ CO_2e}{DDRDP\ GGRF\ Funds\ Requested\ (\$)}$$

- **DDRDP funds requested per portion of GHG reductions attributable to DDRDP funding over 10 years** ($\$/MTCO_2e$); and

- **Portion of the GHG emission reductions attributable to the GGRF funding from another CCI program** ($MTCO_2e$), as applicable.

The **Co-benefits Summary** tab displays the estimated:

- Fossil Fuel Use Reductions (onsite reductions) over 10 years (gallons)
- Renewable Fuel Generation over 10 years (gallons)
- Renewable Energy Generation over 10 years (kWh)

Section C. Documentation

In addition to DDRDP application requirements, applicants for GGRF funding are required to document results from the use of this Quantification Methodology, including supporting materials to verify the accuracy of project-specific inputs.

Applicants are required to provide electronic documentation that is complete and sufficient to allow the calculations to be reviewed and replicated. Paper copies of supporting materials must be available upon request by agency staff.

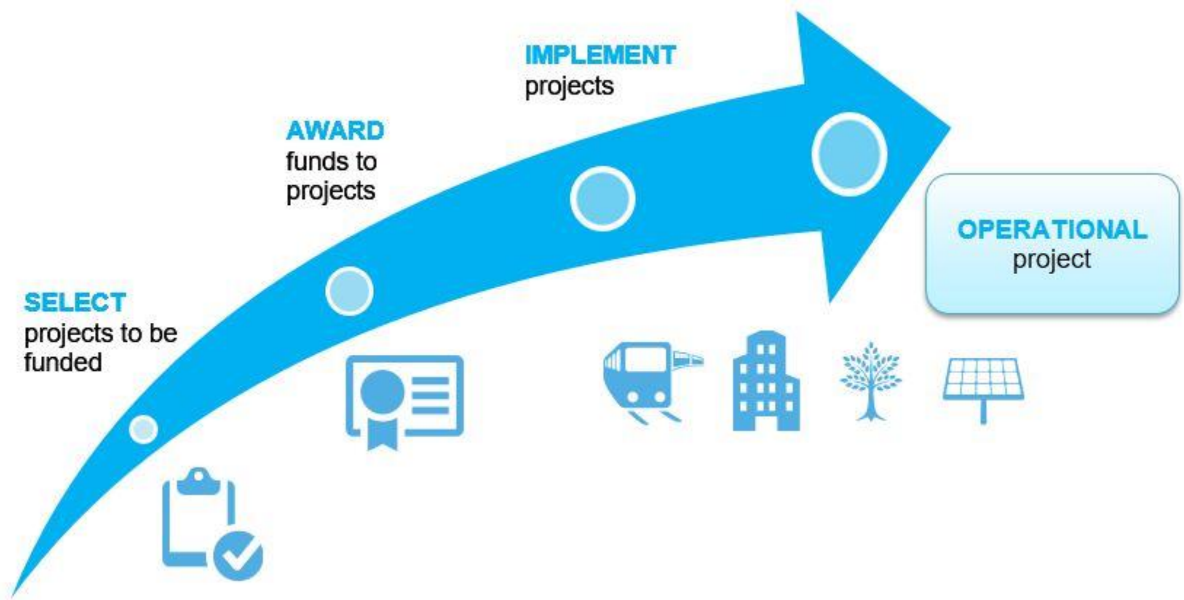
The following checklist is provided as a guide to applicants; additional data and/or information may be necessary to support project-specific input assumptions.

	Documentation Description	Completed
1.	Contact information for the person who can answer project specific questions from staff reviewers on the quantification calculations	
2	Project description, including excerpts or specific references to the location in the main DDRDP application of the project information necessary to complete the applicable portions of the Quantification Methodology.	
3.	Populated DDRDP Calculator Tool file (in .xlsx) with worksheets applicable to the project populated (ensure that all Yellow fields in the 'Project Data Inputs' worksheet are completed and all Gray fields in the 'GHG Summary' and 'Co-benefits' tabs contain calculated values).	
4.	Information necessary and appropriate to substantiate inputs (e.g., documentation of baseline livestock population, fossil fuel and electricity consumption, specifications of BCS design, relevant environmental permits, etc.) must be kept onsite and made available to CDFA or CARB upon request.	

Section D. Reporting after Funding Award

Accountability and transparency are essential elements for all CCI. All administering agencies are required to track project implementation and report on the benefits of those investments. CARB develops tracking and reporting guidance for CCI. The reporting process and requirements are found in Volume 3 of the draft Funding Guidelines.[3] Draft Funding Guidelines Appendices 3.A and 3.B contain detailed reporting requirements that are specific to each project type or administering agency and cover all stages of reporting.

CDFA will submit periodic reports to CARB. The specific data that need to be reported depend on the project type and the stage of project implementation at the time of reporting. Initially, administering agencies must report basic project information and expected benefits. As projects are implemented, administering agencies provide additional information on project status, benefits, and results. When projects are completed, administering agencies submit project closeout reports. A subset of projects, selected by CDFA, will report on project outcomes upon reaching a specified milestone and being considered "operational."



CDFA is required to collect and compile project data from funding recipients, including the net GHG benefit estimated using this Quantification Methodology, co-benefits, and information on benefits to AB 1550[4] Populations. Reported information will be used to

[3] CARB released updated draft Funding Guidelines in August 2017. These draft Funding Guidelines are subject to change based on public input and Board direction. While the draft provides an indication of what is currently required, administering agencies must incorporate all provisions reflected in the draft Funding Guidelines and subsequent Board approved Funding Guidelines.
[4] AB 1550, Gomez, Chapter 369, Statutes of 2016; amending Health and Safety Code Section 39713. Detailed information on AB 1550 requirements is provided in Volume 2 of the draft Funding Guidelines.

demonstrate how the Administration is achieving or exceeding the statutory objectives for CCI. Key variables are highlighted in the Co-benefits Summary tab of the DDRDP Calculator Tool. Funding recipients have the obligation to provide, or provide access to, data and information on project outcomes to CDFA. Applicants should familiarize themselves with the requirements within the DDRDP Program Guidelines, solicitation materials, and grant agreement, as well as the CARB Funding Guidelines.

Section E. References

The following references were used in the development of this Quantification Methodology and the accompanying DDRDP Calculator Tool.

California Air Resources Board. (2014). *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems*. https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.

California Air Resources Board. (2016). *Greenhouse Gas Quantification Methodology for the California Department of Resources Recycling and Recovery Waste Diversion Grant and Loan Program, Greenhouse Gas Reduction Fund Fiscal Year 2015-16*. www.arb.ca.gov/cci-quantification.

UC Davis California Biomass Collaborative. (2016). *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California: FINAL TECHNICAL REPORT to the State of California Air Resources Board*. Stephen Kaffka, et al. http://biomass.ucdavis.edu/wp-content/uploads/2016/06/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf.

UC Davis Biomass Collaborative, U.S. EPA Region 9, and National Risk Management Research Lab Office of Research and Development. (September 2016). *Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies.* http://biomass.ucdavis.edu/wp-content/uploads/2016/11/EPA600R-16099_BiogasTech_Sept2016.pdf.

UC Davis Division of Agriculture and Natural Resources, Committee of Experts on Dairy Manure Management. (2005) *Managing Dairy Manure in the Central Valley of California*. Andrew Chang, et. al. http://groundwater.ucdavis.edu/files/136450.pdf.

Appendix A. Example Project

Introduction

The following is an example project to demonstrate how the FY 2017-18 DDRDP Quantification Methodology would be applied. This example does not provide examples of the supporting documentation that is required of actual project applicants.

Overview of the proposed project

The proposed project is requesting $2 million dollars from DDRDP for a BCS that will primarily utilize recovered biogas for renewable natural gas transportation fuel (via pipeline injection) as part of a cluster. The BCS will be operational one year before the renewable natural gas pipeline injection is operational, so biogas will be combusted in a lean-burn IC engine for electricity generation for the first year of the ten-year project. The project's characteristics to be used as inputs in the DDRDP Calculator Tool are:

- Covered lagoon BCS design;
- Primary biogas end use will be upgrading to renewable natural gas transportation fuel via pipeline injection (90%);
- Secondary biogas destruction device is a lean-burn internal combustion (IC) engine generating electricity (10%).
- Solid separation via stationary screen in both baseline and project scenario;
    - Separated solids are stacked and stored outdoors, and periodically applied to land or used as bedding (solid storage);
- Uncovered effluent pond;
- Located in Kern County;
- $2,000,000 requested from GGRF;
- Previous year average of 2,000 freestall lactating dairy cows, 1,300 dry cows, and 500 heifers;
- Average milk production of 55 lbs/cow/day, with 3.75% milk fat, 3% true protein, and 4.9% lactose;
- All manure sent to anaerobic lagoon in the baseline and to the BCS in the project case, except for separated solids and what is deposited on land in areas where it is not collected;
- 500 gallons of diesel fuel used for manure management support equipment in baseline and project scenarios (support equipment emissions unchanged);
- 300 MWh electricity consumption in baseline scenario and 1,000 MWh estimated for project scenario (increase associated primarily with electricity use in upgrading biogas to pipeline-quality renewable natural gas as well as by stirrers in digester and other BCS support equipment);
- Propane pilot light of IC-engine identified as new combustion source, estimated 30 gallons/yr.

Methods to apply

Step 1: Identify the Project Boundary

The first step in quantifying this example project is to determine the Project Boundary. In order to do this, the applicant should review included sources in Table 2 as it relates to their dairy operations. Applicants must be sure to identify any combustion sources associated with manure management operations prior to the installation of a BCS, identify how these emissions are expected to change as a result of the project, and identify if the project includes any new fossil-fuel combustion sources.

In this example, there are diesel emissions associated with the collection of manure and support equipment; however, the quantity of diesel fuel combusted is not expected to change by installing a covered lagoon BCS. This assumption will not be true for all project designs, such as if manure is trucked to a centralized digester or separated solids in the project are handled in a way different from the baseline that increases diesel fuel. The only new fossil fuel combustion source in this example is a propane pilot light in the IC engine. While the BCS in this example will produce on-site electricity, the applicant must still estimate how the BCS installation will impact electricity usage at the dairy and estimate electricity consumption associated with biogas clean-up for pipeline injection. The applicant in this example estimated a significant increase in electricity demand primarily associated with the upgrading of biogas for pipeline injection, as well as some on-site demand associate with the BCS (such as stirrers). The benefit of the renewable electricity generated from the BCS is calculated separately.

Step 2: Determine the DDRDP Calculator Tool Inputs Needed

Step 2 of this Quantification Methodology requires applicants to enter project-specific information into the DDRDP Calculator Tool. First, download and open the calculator tool from www.arb.ca.gov/cci-quantification. The applicant begins by reading the “Read Me” tab and enters project contact information. Next, the applicant will click on the “Project Data Inputs” tab and enter required project information.

Below are a series of screenshots of the “Project Data Inputs” tab of the DDRDP Calculator Tool. The fields highlighted yellow are required for all projects, while the fields highlighted green may apply to some projects. Where input fields do not apply to the applicants project, they may be left blank or a “0” value may be input.

The project description entry fields identify (1) the type of BCS, (2a-d) biogas destruction device and percent biogas destruction, (3a-b) solid separation system, (4) presence of an uncovered effluent pond, (5) project location, (6a-b) DDRDP and total GGRF funds requested, and (7a-d) milk production characteristics. For each input, the applicant either selects from a drop-down list or enters a value.

If there is more than one biogas destruction device as in this example, the applicant will select both a primary and a secondary destruction device on this screen, and input the percent of biogas expected to be destroyed by each device. The percent destroyed in each is estimated over a ten year period. If there is only one destruction device, the applicant enters 100% for the primary biogas destruction device. If any destruction device is a boiler, the applicant will also complete an additional “Boiler Worksheet” tab.

Input Proposed Project Information

1. Biogas Control System (BCS)	Covered Lagoon		
2a. Primary Biogas Destruction Device	Upgrade and use of gas as CNG/LNG fuel via pipeline injection	90%	2b. % Biogas destroyed in primary destruction device (over 10 yrs)
2c. Secondary Biogas Destruction Device	Lean-burn Internal Combustion Engine	10%	2d. % Biogas destroyed in secondary destruction device (over 10 yrs)
3a. Baseline Solid Separation	Stationary Screen		
3b. BCS Solid Separation	Stationary Screen		
4. Uncovered Effluent Pond?*	Yes		
5. Project Location (county)	Kern		
6a. DDRDP GGRF $ Requested	$2,000,000.00		
6b. Total GGRF $ Requested	$2,000,000.00		
7a. Milk Fat (%)	3.75%		
7b. Milk true Protein (%)	3.00%		
7c. Milk Lactose (%)	4.90%		
7d. Milk Produced (lbs/cow/day)	55		
ECM (kg/cow/day)	24.61		
10 yr ECM (mt)	179,774		

Applicants next enter data for the current practices (baseline scenario). For input 8, applicants enter the number of livestock by category. In this example, all the lactating dairy cows are housed in freestalls, so nothing is entered for “Dairy Cows (open lot corrals).”

Default input 9a is a fixed default value for the % of manure volatile solids deposited on land and not entering a wet/anaerobic environment. Applicants do not enter a value in this field.

Default input 9b is a fixed default value for the % of manure volatile solids separated prior to entry into a wet/anaerobic environment and sent to any other treatment or storage system or end use. The tool automatically provides a default % of volatile solids separated and sent to an alternative storage/treatment system based on the solid separation technology identified by the applicant. The applicant must select the practice that best characterizes how separated solids will be stored and/or treated based on the definitions provided. In this example, separated solids are stacked and stored outdoors: the applicant selects “solid storage.”

Input 9c is an optional input that allows applicants to identify whether any other manure volatile solids are separated or collected and sent to another predominantly non-anaerobic treatment/storage system. For example, this might apply if there is more than one solid separation process in sequence at the dairy, or if some manure is scraped rather than flushed. In this example, all other manure volatile solids are flushed into an anaerobic lagoon, so this input is left blank.

For input 9d, applicants enter the fraction of manure volatile solids that enter the anaerobic lagoon. The input value for each cell should be 100% less the sum of the values in 9a-9c for that cell's row, so that all cells should sum to 100% in the "Total Volatile Solids" column.

Finally, the applicant will input baseline electricity (input 10) and fuel consumption (input 11) for all sources associated with manure collection, storage and treatment (see Table 2) by fuel type.

	Baseline Manure Management -- Enter data regarding management practices using averages of preceding 12 months					
	8. Enter number of livestock by category	9a. Percent of manure volatile solids (VS) deposited on land and not entering wet/anaerobic environment	9b. Percent of VS from solid separation prior to wet/anaerobic environment and sent to other treatment/storage practice	9c. (if applicable) Enter % VS sent to any other non-anaerobic treatment/storage	9d. Enter % VS entering wet/anaerobic system (e.g., lagoon, storage pond) by livestock category	Total Volatile Solids must sum to 100%
Dairy Cows (freestall)	2,000	20%	13.6%		66.4%	100%
Dairy Cows (open lot corrals)		70%	5.1%			
Dry cows	1,300	70%	5.1%		24.9%	100%
Heifers	500	70%	5.1%		24.9%	100%
		Pasture / Dirt	solid storage			
			Identify current practice for separated solids	Identify other current treatment/storage practice		

Energy Use Associated with Current Waste Management Practices

10. Electricity Consumed	MWh/yr	300
11a. Fuel Consumed	Diesel (Distillate No. 1 or 2, gal.)	500
11b. Fuel Consumed		
11c. Fuel Consumed		

*Select Applicable Fuel(s) from List.

Just as with the baseline scenario, applicants next enter information for the project scenario describing planned conditions and practices after the installation of a biogas control system. For all projects, the livestock population is assumed to remain constant over the life of the project. In this example, practices regarding solid separation are not expected to change as a result of the project, so the default inputs 12a and 12b, as well as the optional input 12c, are identical to the values in the baseline scenario. The percent of manure volatile solids entering the covered lagoon digester (input 12d) is the same as entered the lagoon in the baseline.

The applicant next enters estimated electricity (input 13) and fuel consumption (input 14a-c) after the installation of the biogas control system. It includes all sources associated with manure collection, storage and treatment, as well as associated with operation of the BCS and biogas cleanup (see Table 2). In this example, the electricity consumption is expected to increase significantly due to the energy demands of the biogas upgrading process for pipeline injection as well as new demand for operation of the BCS onsite. A new fossil-fuel source (propane) has been included, but diesel consumption is expected to remain unchanged.

Input 14 is a table to list relevant CO_2 emission sources and is located at the bottom of the screen. This is intended to be a descriptive list to provide supplemental information, and is not used directly in the emissions calculations. In the DDRDP Calculator Tool, emission sources are aggregated by fuel-type for the purposes of calculations (e.g., diesel, natural gas, propane, etc.), but individual sources must still be listed at the bottom to identify what sources combusted each of the fuels identified. In this table, applicants also identify from a drop-down list whether each source is a new source (after installation of the BCS), or whether there is expected to be an increase, decrease or no change in fuel consumption and GHG emissions as a result of installing the BCS. In this example, there are emissions from diesel manure collection equipment, which are not expected to change, and a new propane source.

Project Manure Management -- Estimate Data Regarding Management Practices after Installation of BCS						
	Number of Livestock by Category	12a. Percent of manure volatile solids (VS) deposited on land and not entering wet/anaerobic environment	12b. Percent of VS from solid separation prior to BCS sent to other treatment/storage practice	12c. (if applicable) Enter % VS sent to any other non-anaerobic treatment/storage	12d. Enter % VS sent to (managed in) biogas control system by livestock category	Total Volatile Solids must sum to 100%
Dairy Cows (freestall)	2,000	20%	13.6%		66.4%	100%
Dairy Cows (open lot corrals)	0	70%	5.1%			
Dry Cows	1,300	70%	5.1%		24.9%	100%
Heifers	500	70%	5.1%		24.9%	100%
		Pasture / Dirt	solid storage			
			Identify Post-Project Practice for Separated Solids	Identify Other Post-Project Practice		

Projected Energy Usage after Installation of Biogas Control System		
13. Electricity Consumed	MWh/yr	1,000
14a. Fuel Consumed	Diesel (Distillate No. 1 or 2, gal.)	500
14b. Fuel Consumed	Propane / LPG (gallons)	30
14c. Fuel Consumed		
	*Select Applicable Fuel(s) from List.	

15. Description of Stationary and Mobile Sources associated with Manure Management Activities included in GHG Emission Calculations

Source Description	Fuel Type	Change in emissions relative to Baseline
Manure collection equipment (e.g., trucks, tractors)	Diesel (Distillate No. 1 or 2, gal.)	No change
Supplemental fuel for engine	Natural Gas (MMBtu)	New source

Step 3: Estimate Net GHG Emission Reductions and Co-benefits Calculated using the DDRDP Calculator Tool

After inputting all the required data, the applicant will click on the “GHG Summary” tab of the worksheet. The “GHG Summary” tab displays the results calculated by the DDRDP Calculator Tool.

The first seven blue rows contain the metrics required to be reported by the project applicant. In this example, baseline GHG emissions were calculated to be 12,106 metric tons CO_2e/yr.[5] After installation of the BCS, GHG emissions are expected to be reduced to 3,089 mtCO_2e/yr. There is also an additional benefit of avoiding 1,396 mtCO_2e/yr through the displacement of diesel transportation fuel and 44 mtCO_2e/yr through the generation of renewable electricity. This results in a net GHG reduction of 10,456 mtCO_2e/yr. Over the life of the project, this yields a total estimated net GHG reduction of 104,565 mtCO_2e.

The total GHG emission reduction divided by the calculated energy corrected milk production rate yields 0.58 mtCO_2e / mtECM. For this project, both the DDRDP GGRF and total GGRF funds requested are the same, with 0.052 mtCO_2e reduced per dollar of GGRF requested. All of the calculated GHG reductions are thus attributable to the DDRDP grant funds (rather than apportioned among multiple CCI programs), with the project requesting $19.13 from DDRDP per metric ton CO_2e reduction.

[5] “Carbon dioxide equivalent” or “CO2e” means the number of metric tons of CO2 emissions with the same global warming potential as one metric ton of another greenhouse gas. "Global warming potential" or "GWP" means the ratio of the time-integrated radiative forcing from the instantaneous release of one kilogram of a trace substance relative to that of one kilogram of a reference gas, i.e., CO2. “Metric tons” are abbreviated as “mt” rather than “MT” in this Quantification Methodology to be consistent with the Livestock Protocol (CARB 2014).

Total project GHG emission reductions over 10 years	**Total estimated project GHG reductions**	**104,565**	**mtCO2e**
Total GHG reduction per unit energy-corrected milk over 10 years	**GHG/ECM**	**0.58**	**mtCO2e/ mt ECM**
Total GHG reduction per total GGRF dollars requested over 10 years	**GHG/(Total GGRF $)**	**0.052**	**mtCO2e/$ requested**
Portion of total GHG emission reductions attributable to the DDRDP funding	**DDRDP GHG**	**104,565**	**mtCO2e**
Total GHG reduction per $ DDRDP GGRF grant funds requested over 10 years	**GHG/(DDRDP GGRF $)**	**0.052**	**mtCO2e/$ requested**
DDRDP funds requested per portion of GHG reductions attributable to DDRDP funding over 10 years	**(DDRDP GGRF $)/ DDRDP GHG**	**$19.13**	**$ requested / mtCO2e**
Portion of the GHG emission reductions attributable to the GGRF funding from other California Climate Investments program(s), if applicable	**GHG reductions attributable to other CCI programs**	**0**	**mtCO2e**

Baseline CH4 emissions from anaerobic storage/treatment systems	BE_CH4 AS	11,704.38	mtCO2e/yr
Baseline CH4 emissions from non-anaerobic storage/treatment systems (including separated solids)	BE_CH4 NAS	310.30	mtCO2e/yr
Baseline CO2 emissions associated with current manure mgmt practices	BE_CO2 other	90.97	mtCO2e/yr
Total Annual Baseline Emissions	**BE_Total**	**12,106**	**mtCO2e/yr**
Project CH4 emissions from biogas collection and destruction inefficiencies	PE_CH4 BCDE	1,217.62	mtCO2e/yr
Project CH4 emissions from effluent pond	PE_CH4 EP	1,270.13	mtCO2e/yr
Project CH4 emissions from non-anaerobic storage/treatment systems (including separated solids)	PE_CH4 NAS	310.30	mtCO2e/yr
Project CO2 emissions associated with manure mgmt practices after installation of BCS	PE_CO2	290.64	mtCO2e/yr
Total Annual Project Emissions	**PE_Total**	**3,089**	**mtCO2e/yr**
Total Annual Direct Emission Reductions	**DER_Total**	**9,017**	**mtCO2e/yr**
Avoided CO2 emissions from upgrade to biomethane (if applicable)	AD_CO2	1,395.74	mtCO2e/yr
Avoided CO2 emissions from boiler thermal energy use (if applicable)	ANG_CO2	0.00	mtCO2e/yr
Avoided CO2 emissions from electricity generation (if applicable)	AEG_CO2	43.78	mtCO2e/yr
Total Annual Project Emission Reductions	**Project Annual Total**	**10,456**	**mtCO2e/yr**

The applicant may also click on the “co-benefits” to locate information about additional estimated benefits of the proposed project. The FY 2017-18 DDRDP Calculator Tool includes estimates of onsite fossil fuel reductions and renewable fuel and/or electricity generation. This project is expected to produce 1,017,451 diesel equivalent gallons of renewable transportation fuel and 1,536,226 kWh of renewable electricity over 10 years. Onsite fossil fuel use is expected to increase by 199 diesel equivalent gallons.

Fossil Fuel Use Reductions (onsite reductions) over 10 years	**FRg**	**-199**	**gallons***
Renewable Fuel Generation over 10 years	**RFG**	**1,017,451**	**gallons***
Renewable Energy Generation over 10 years	**REG**	**1,536,226**	**kWh**

*diesel gallons equivalent

Appendix B. Equations Supporting the DDRDP Calculator Tool

Methods used in the DDRDP Calculator Tool for estimating the net GHG emission reductions by activity type are provided in this appendix. The GHG emission reductions from the project are quantified within the DDRDP Calculator Tool using the equations below.

The GHG emission reductions from DDRDP projects is calculated using Equation 13 as the difference between the baseline and project scenarios plus the additional GHG benefit of electricity generation, avoided diesel emissions from the use of biomethane as a transportation fuel or avoided natural gas emissions from the recovery and use of thermal energy from a boiler.

A. Calculation of annual baseline methane emissions

Baseline scenario methane emissions represent the emissions within the Project Boundary that would have occurred without the installation of the BCS. Applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors. Baseline emissions must be calculated according to the manure management system in place prior to installing the BCS.

The procedure to determine the project baseline methane emissions uses Equations 1, 2 and 3, with Equations 2 and 3 as inputs to Equation 1. Equation 2 calculates CH_4 emissions from anaerobic manure storage/treatment systems (e.g. anaerobic lagoons, storage ponds, etc.) based on project-specific mass of volatile solids degraded by the anaerobic storage/treatment system and available for methane conversion. The equation incorporates the effects of temperature and accounts for the retention of volatile solids. Equation 3 applies to predominantly non-anaerobic storage/treatment systems and is used to calculate emissions from separated solids and other volatile solids not sent to an anaerobic lagoon or storage pond. Both Equations 2 and 3 reflect basic biological principles of methane production from available volatile solids, determine methane generation for each livestock category, and account for the extent to which the waste management system manages each category's manure. The calculation procedure uses a combination of project-specific variables and default factors:

Population – P_L

The procedure for establishing population values requires the applicant to differentiate between livestock categories ('L') such as lactating dairy cows, dry cows (non-milking dairy cows), heifers, etc., to account for differences in methane generation across livestock categories. The population of each livestock category is monitored on a monthly basis and averaged for an annual total population for the previous 12 months.

Factors that are specific to livestock categories are described below, denoted with the subscript “L” and covered in Tables C.2 and C.3.

Volatile Solids – VS_L
This value represents the daily organic material in the manure for each livestock category and consists of both biodegradable and non-biodegradable fractions. The VS content of manure is a combination of excreted fecal material (the fraction of a livestock category’s diet consumed and not digested) and urinary excretions, expressed in a dry matter weight basis (kg/animal).

Average Weight – $Mass_L$
This value is the annual average live weight of the animals, per livestock category. Typical Average Mass (TAM) values are used.

Maximum Methane Production – $B_{0,L}$
This value represents the maximum methane-producing capacity of the manure, differentiated by livestock category (‘L’) and diet. Default $B_{0,L}$ factors are used.

Manure Management System – MS
The MS value apportions volatile solids from each livestock category to an appropriate manure management system component (‘S’). The MS value accounts for the operation’s multiple types of manure management systems and is expressed as a percent (%), relative to the total amount of volatile solids produced by the livestock category. As waste production is normalized for each livestock category, the percentage should be calculated as percent of population for each livestock category. For example, a dairy operation might send 85% of its milking cows’ waste to an anaerobic lagoon and 15% to a corral. In this example, an MS value of 85% would be assigned to Equation 2 and 15% to Equation 3.

The MS value also accounts for the fraction of volatile solids separated through a solid separation technology. Default values are used to calculate an MS value for separated solids.

Methane Conversion Factor – MCF
Each manure management system component has a volatile solids-to-methane conversion efficiency, which represents the degree to which maximum methane production (B_0) can be achieved. Default MCF values for non-anaerobic manure storage/treatment are used for Equation 3.

Equation 1: Baseline Methane Emissions

$$BE_{CH4} = BE_{CH4,AS} + BE_{CH4,non-AS}$$

Where,			Units
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic storage/treatment systems	$mtCO_2e/yr$
$BE_{CH4,non-AS}$	=	Total annual project baseline methane emissions from predominantly non-anaerobic storage/treatment systems	$mtCO_2e/yr$

Equation 2: Baseline Methane Emissions from Anaerobic Storage / Treatment

$$BE_{CH4,AS} = \sum_{l,i} (VS_{\deg AS,l,i} \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			Units
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems	$mtCO_2e/yr$
$VS_{degAS,L,i}$	=	Monthly volatile solids degraded in anaerobic manure storage/treatment system 'AS' from livestock category 'L' in month 'i'	kg dry matter
$B_{0,L}$	=	Maximum methane producing capacity of manure for livestock category 'L'	m^3 CH_4/kg of VS
0.68	=	Density of methane (1 atm, 60ºF)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential of methane[ix]	

With:

$$VS_{\deg,AS,L,i} = f_i \times VS_{avail,AS,L,i}$$

Where,			Units
$VS_{deg,AS,L,i}$	=	Volatile solids degraded by anaerobic manure storage/ treatment system 'AS' by livestock category 'L' in month "i"	kg dry matter
$VS_{avail,AS,L,i}$	=	Monthly volatile solids available for degradation from anaerobic manure storage/treatment system 'AS' by livestock category 'L'	kg dry matter
f_i	=	The van't Hoff-Arrhenius factor = "the proportion of volatile solids that are biologically available for conversion to methane based on the monthly average temperature of the system"	

With:

$$f_i = MIN\left(\exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right], 0.95\right)$$

Where,			Units
f	=	The van't Hoff-Arrhenius factor for month "i"	
E	=	Activation energy constant (15,175)	cal/mol
T_1	=	303.16	Kelvin
T_2	=	Monthly average ambient temperature (K = °C + 273). If $T_2 < 5$ °C then f = 0.104[x]	Kelvin
R	=	Ideal gas constant (1.987)	cal/K-mol

Equation 2: Baseline Methane Emissions from Anaerobic Storage / Treatment Systems (continued)

And:

$$VS_{avail,AS,L,i} = \left(VS_L \times P_L \times MS_{AS,L} \times dpm_i \times 0.8\right) + \left(VS_{avail,AS,L,i-1} - VS_{\deg,AS,L,i-1}\right)$$

Where,			Units
$VS_{avail,AS,L,i}$	=	Volatile solids available for degradation in anaerobic storage/treatment system 'AS' by livestock category 'L' in month 'i'	kg dry matter
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis.	kg/ animal/ day
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$MS_{AS,L}$	=	Fraction of volatile solids sent to (managed in) anaerobic manure storage/treatment system 'AS' from livestock category 'L'	%
dpm_i		Days per month 'i'	days
0.8	=	System calibration factor	
$VS_{avail,AS,L,i-1}$	=	Previous month's volatile solids available for degradation in anaerobic system 'AS'	kg
$VS_{deg,AS,L,i-1}$	=	Previous month's volatile solids degraded by anaerobic system 'AS'	kg

With:

$$VS_L = VS_{table} \times \frac{Mass_L}{1000}$$

Where,			
VS_L	=	Volatile solid excretion on a dry matter weight basis	kg/ animal/ day
VS_{table}	=	Volatile solid excretion	kg/ day/ 1000kg
$Mass_L$	=	Average live weight for livestock category 'L'	

Equation 3: Baseline Methane for Non-Anaerobic Storage/Treatment Systems

$$BE_{CH4,non\text{-}AS} = \sum_{s,l}(P_l \times MS_{non\text{-}AS,s,l} \times VS_l \times 365.25 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			Units
$BE_{CH4,non\text{-}AS}$	=	Total annual baseline methane emissions from predominantly non-anaerobic storage/treatment systems	$mtCO_2e$
P_L	=	Annual average population of livestock category ‘L’ (based on monthly population data)	
$MS_{non\text{-}AS,s,L}$	=	Fraction of volatile solids from livestock category ‘L’ managed in non-anaerobic storage/treatment system ‘s’	%
VS_L	=	Volatile solids produced by livestock category ‘L’ on a dry matter basis	kg/ animal/ day
365.25	=	Days in a year	days
MCF_s	=	Methane conversion factor for non-anaerobic storage/treatment system ‘s’	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category ‘L’	m^3 CH_4/kg of VS dry matter
0.68	=	Density of methane (1 atm, 60ºF)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	
S	=	Manure treatment/storage system	

B. Estimation of Project Methane Emissions

Even after installation of a BCS, some methane will still be emitted to the atmosphere through biogas collection and destruction inefficiencies and periods of equipment malfunction. This Quantification Methodology includes an estimate of methane released to the atmosphere through biogas collection and destruction inefficiencies using Equation 4.

For projects where BCS design includes an uncovered effluent pond, project methane emissions from residual volatile solids in the effluent pond(s) are calculated using Equation 5. If a project design does not include an effluent pond, or if the effluent pond is covered and methane from the effluent pond is recovered as part of the BCS design, no effluent pond emissions are calculated.

Applicants must also calculate CH_4 emissions from any volatile solids sent to other waste management and storage systems after the installation of a BCS (including but not limited to separated solids) using Equation 6.

Total project methane emissions after installation of a BCS are summed in Equation 7.

Equation 4: Estimated Annual Methane Emissions from the BCS

$$PE_{CH4,\ BCDE} = BE_{CH4,\ AS} \times [(1/BCE) - BDE]$$

Where,			Units
$PE_{CH4,BCDE}$	=	Estimated project methane emissions due to methane capture and destruction inefficiencies	$mtCO_2e/yr$
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems	$mtCO_2e/yr$
BCE	=	Biogas collection efficiency	fraction (0-1)
BDE	=	Biogas destruction efficiency	fraction (0-1)

Equation 5: Estimated Project Methane Emissions from the BCS Effluent Pond(s)

$$PE_{CH4,EP} = VS_{EP} \times 365 \times MCF_{EP} \times 0.68 \times 0.001 \times 25$$

Where,			Units
$PE_{CH4,EP}$	=	Methane emissions from the effluent pond after installation of BCS	$mtCO_2e$
VS_{EP}	=	Volatile solids to effluent pond	Kg/day
365.25	=	Days in a year	days
MCF_{EP}	=	Methane conversion factor for liquid/slurry	%
0.68	=	Density of methane (1 atm, 60ºF)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	

with:

$$VS_{EP} = \sum_{l} (VS_l \times P_l \times B_{0,l} \times MS_{l,BCS}) \times 0.3$$

Where,			Units
VS_{EP}	=	Volatile solids to effluent pond	Kg/day
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L'	m^3 CH_4/kg of VS dry matter
$MS_{L,BCS}$	=	Percent of manure from livestock category 'L' managed in the BCS	%
0.3	=	Default value representing the amount of VS that exits the digester as a percentage of the VS entering the digester	

Equation 6: Estimated Project Methane for Non-Anaerobic Storage/Treatment Systems

$$PE_{CH4,non-BCS} = \sum_{s,l}(P_l \times MS_{non-BCS,s,l} \times VS_l \times 365 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			Units
$PE_{CH4,non-BCS}$	=	Total annual methane emissions from other waste storage/treatment systems after installation of BCS	$mtCO_2e$
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$MS_{non-BCS,s,L}$	=	Percent of volatile solids from livestock category 'L' managed in non-BCS storage/treatment system 's'	%
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
365.25	=	Days in a year	days
MCF_s	=	Methane conversion factor for non-anaerobic storage/treatment system 's'	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L'	m^3 CH_4/kg of VS dry matter
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	

Equation 7: Total Project Methane Emissions

$$PE_{CH4} = PE_{CH4,BCDE} + PE_{CH4,EP} + PE_{CH4,non-BCS}$$

Where,			Units
PE_{CH4}	=	Estimated methane emissions after installation of BCS	$mtCO_2e$/yr
$PE_{CH4,BCDE}$	=	Estimated project methane emissions due to methane capture and destruction inefficiencies	$mtCO_2e$/yr
$PE_{CH4,EP}$	=	Methane emissions from the effluent pond after installation of BCS	$mtCO_2e$/yr
$PE_{CH4,non-BCS}$	=	Methane emissions from other waste storage/treatment systems after installation of BCS	$mtCO_2e$/yr

C. Calculation of anthropogenic carbon dioxide emissions and emission reductions associated with the BCS

Carbon dioxide emission sources associated with manure management activities include but are not limited to: electricity use by pumps and equipment, fossil fuel generators used to destroy biogas or power pumping systems or milking parlor equipment; flares; tractors that operate in barns or freestalls; on-site manure hauling trucks; or vehicles that transport manure off-site. For the purposes of calculating baseline CO_2 emissions, applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors.

Use Equation 8 to calculate baseline carbon dioxide emissions. Note: Carbon dioxide emissions from the combustion of biogas are considered biogenic emissions and are excluded from the Project Boundary.

<u>Stationary and Mobile Source Emissions</u>: Carbon dioxide emissions associated with manure management activities may decrease, increase or remain unchanged as a result of installing a BCS. Applicants should pay particular attention to any changes in manure collection or transport practices, such as if manure is trucked to a central digester or compost is trucked offsite, and if there are any new fossil fuel combustion sources, such as if natural gas or other fuels are co-fired in an engine or boiler during periods of low biogas production.

Applicants must include a list of all relevant CO_2 emission sources by fuel type. Baseline emissions are calculated based on previous 12-months fuel consumption by fuel type. Project emissions are estimated by the applicant. Applicants must include an explanation of how installation of a BCS will affect fuel consumption by these sources, and estimates for any new sources.

<u>Indirect Electricity Emissions</u>: Projects must include indirect emissions associated with electricity use in the baseline using data from the previous 12 months of dairy operation. Applicants must also estimate annual electricity consumption after the installation of a BCS. In many cases, this is expected to be higher than baseline electricity consumption, as many BCS designs include components (such as tank stirring/mixing) powered by electricity rather than fossil fuels. Likewise, upgrading biogas for use as biomethane transportation fuel may involve a significant increase in electricity consumption.

When a BCS project includes generation of electricity, avoided fossil CO_2 emissions are calculated and credited using Equation 10. However, even for such projects applicants must *not* input a 0 for electricity consumption in Equation 9, but rather input actual estimated electricity consumption.

Equation 8: Baseline Carbon Dioxide Emissions From Mobile and Stationary Support Equipment, and Electricity Consumption

$$BE_{CO_2} = \left(\sum_c QE_c \times EF_{CO_2,e}\right) + \left[\left(\sum_c QF_c \times EF_{CO_2,f}\right) \times 0.001\right]$$

Where,			Units
BE_{CO2}	=	Anthropogenic carbon dioxide emissions from electricity consumption, and mobile and stationary combustion sources	$mtCO_2$
QE_c	=	Quantity of electricity consumed for each emissions source "c"	MWh/yr
$EF_{CO2,e}$	=	CO_2 emission factor *e* for electricity used[xi]	$mtCO_2$/ MWh
QF_c	=	Quantity of fuel consumed for each mobile and stationary emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor *f*	kg CO_2/ MMBtu or kg CO_2/gal
c	=	CO_2 emission source	
0.001	=	Conversion factor from kg to metric tons	

Equation 9 is used to calculate Project CO_2 emissions. Any source included in the baseline must be included in the project, unless CO_2 emissions from that source are reasonably expected to be zero after installation of a BCS. When applying Equation 9, individual sources may be aggregated by total electricity consumption and by fuel type.

Equation 9: Project Carbon Dioxide Emissions From Mobile and Stationary Equipment, and Electricity Consumption

$$PE_{CO_2} = \left(\sum_c QE_c \times EF_{CO_2,e}\right) + \left[\left(\sum_c QF_c \times EF_{CO_2,f}\right) \times 0.001\right]$$

Where,			Units
PE_{CO2}	=	Anthropogenic carbon dioxide emissions from electricity consumption and mobile and stationary combustion sources	$mtCO_2$
QE_c	=	Quantity of electricity consumed for each emissions source "c"	MWh/yr
$EF_{CO2,e}$	=	CO_2 emission factor *e* for electricity used	$mtCO_2$/ MWh
QF_c	=	Quantity of fuel consumed for each mobile and stationary emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor *f*	kg CO_2/ MMBtu or kg CO_2/gal
c	=	CO_2 emission source	
0.001	=	Conversion factor from kg to metric tons	

Projects that utilize recovered biogas for electricity generation may calculate the benefit of avoided grid CO_2 emissions using Equation 10. Consistent with other CARB

Quantification Methodology, a default electrical conversion efficiency 0.3 is assumed for internal combustion engines and turbines.[xii] A default electrical conversion efficiency of 0.45 is assumed for fuel cells.[xiii] There is also an adjustment factor included to account for expected higher than baseline methane production levels in plug-flow and complete mix/tank digester designs. The adjustment factor is 1.12 for such BCS designs, consistent with assumptions in the UC Davis (2016) *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California* technical report.[xiv]

Equation 10: Avoided fossil CO2 emissions associated with use of recovered biogas for electricity generation.

$$AEG_{CO_2} = (BE_{CH4} - PE_{CH4}) \div 25 \times 1000 \times AF \times EC_{CH4} \times NEE \times EEF$$

Where,			Units
AEG_{co2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$mtCO_2e/yr$
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $mtCO_2e$ back to $mtCH_4$)	$mtCO_2e/ mtCH_4$
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
1000	=	Conversion from metric tons to kg	Kg/mt
EC_{CH4}	=	Energy content of methane = 13.89	$kWh/kgCH_4$
NEE	=	Net electrical conversion efficiency. This QM assumes a default value of 0.3 for IC engines and turbines, and 0.45 for fuel cells.	
EEF	=	California electricity grid-average CO_2 emission factor	$mtCO_2/ kWh$

Projects that upgrade recovered biogas to biomethane for use as transportation fuel, either onsite or through pipeline injection, may calculate the benefit of avoided fossil diesel fuel using Equation 11. This Quantification Methodology assumes that biomethane used as transportation fuel will avoid diesel truck GHG emissions. An energy balance approach is used, whereby the energy content of recovered CH_4 is assumed to avoid the use of an energy-equivalent quantity of gallons of diesel fuel. A recovery factor of 90% is included to account for the fraction of methane in biogas that is ultimately recovered in upgrading to biomethane, consistent with a UC Davis (2016) report on the evaluation of biogas management technologies.[xv] An adjustment factor is also included to account for greater than baseline methane production levels expected in plug-flow and complete mix/tank digester designs where the BCS is heated above ambient temperatures. The adjustment factor is 1.12 for such BCS designs, consistent with assumptions in the UC Davis (2016) report cited earlier.[xvi]

Equation 11: Avoided diesel carbon dioxide emissions from use of recovered biogas for transportation fuel.

$$AD_{CO_2} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times RF \times EC_{CH4} \div EC_D \times EF_D \times 0.001$$

Where,			Units
AD_{CO2}	=	Avoided diesel fossil CO2 emissions	$mtCO_2e/yr$
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $mtCO_2e$ values calculated previously back to $mtCH_4$)	
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
RF	=	Recovery Factor of 0.9. Assumption that 90% of methane in biogas is ultimately recovered as biomethane.	
EC_{CH4}	=	Energy content of CH_4	MMbtu/mt CH_4
EC_D	=	Energy content of diesel fuel	MMBtu/ gallon
EF_D	=	Emission factor for diesel fuel	$kgCO_2$ / gallon
0.001		Conversion factor	mt CO_2 / kg CO_2

Projects that combust biogas in a boiler and utilize recovered thermal energy in non-BCS related processes that reduce demand for fossil-fuel based energy may calculate the benefit of avoided CO_2 emissions using Equation 12. This methodology assumes the reduced thermal energy demand would have been produced by combustion of fossil natural gas in a conventional boiler with comparable efficiency, validating a stoichiometric approach. An adjustment factor is included to account for expected higher than baseline methane production levels in plug-flow and complete mix/tank digester designs.[xvii]

The utilization factor (UF) in Equation 12 represents the fraction of thermal energy from recovered biogas that is used in processes that replace fossil-based thermal energy. The fraction of thermal energy used to maintain digester temperature or to heat/dry digestate or separated manure solids is excluded from the UF. The UF also excludes the fraction of time when thermal energy produced by the boiler is not used in applicable processes. For example, if thermal energy from the boiler is used only in seasonal winter heating, the UF would not be expected to be more than 25-30%. Likewise, if the boiler operates continuously but recovered thermal energy is used for heating in a process that operates only 12 hours a day, than the UF should not exceed 50%. Applicants who identify boiler as the biogas destruction device will also complete the “Boiler Worksheet” in the DDRDP Calculator tool to assist in the calculation of avoided fossil natural gas emissions.

Equation 12: Avoided fossil natural gas carbon dioxide emissions through use of recovered thermal energy from combustion of biogas in a boiler.

$$ANG_{CO_2} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times UF \times 2.74$$

Where,			Units
AEG_{co2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$mtCO_2e/yr$
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $mtCO_2e$ back to $mtCH_4$)	$mtCO_2e/$ $mtCH_4$
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
UF	=	Utilization factor. Fraction of thermal energy from boiler used in non-BCS processes that directly reduce fossil natural gas demand.	fraction (0-1)
2.74	=	Molecular weight of CO_2 / molecular weight of CH_4.	$mtCO_2$ / $mtCH_4$

D. Calculation of the net GHG emission reduction attributable to the project

GHG emission reductions from a DDRDP project are quantified using Equation 13 by summing the baseline methane and anthropogenic carbon dioxide emissions, subtracting from this any remaining project emissions, and adding to this the avoided carbon dioxide emissions from the utilization of recovered biogas. Emission reductions are aggregated over a 10 year period, the minimum project life-time.

Equation 13: Project GHG Emission Reductions from Installing a BCS

$$ER = (BE_{CH4} + BE_{CO2} - PE_{CH4} - PE_{CO2} + AD_{CO_2} + ANG_{CO_2} + AEG_{CO_2}) \times 10$$

Where,			<u>Units</u>
ER	=	Calculated net GHG emission reduction over 10 years	$mtCO_2e$
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
BE_{CO2}	=	Baseline carbon dioxide emissions associated with manure management from stationary and mobile sources	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
PE_{CO2}	=	Estimated carbon dioxide emissions associated with manure management from stationary and mobile sources after instillation of BCS	$mtCO_2e/yr$
AD_{CO2}	=	Avoided diesel fossil CO2 emissions	$mtCO_2e/yr$
ANG_{CO2}	=	Avoided natural gas fossil CO2 emissions	$mtCO_2e/yr$
AEG_{CO2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$mtCO_2e/yr$
10	=	Minimum project lifetime	years

E. Calculation of Other Reported Metrics

In addition to a calculation of the total GHG emission reductions over 10 years, the DDRDP Calculator Tool also computes the following metrics:

- GHG reduction per unit energy-corrected milk produced by operation; and
- GHG reduction per $ GGRF grant money invested.

The calculation of GHG reduction per unit energy-corrected milk uses the energy corrected milk production calculated using Equation 14:

Equation 14: Energy-Corrected Milk (ECM)

$$ECM = \frac{(\text{Fat} \times 41.65) + (\text{Protein} \times 24.13) + (\text{Lactose} \times 21.60) - 11.72}{1000} \times \frac{2.204 \times \text{Milk}}{0.721}$$

Where,			Units
ECM	=	Energy-Corrected Milk	kg/cow/d
Fat	=	Milk fat %	%
41.65	=	Energetic value for fat	
Protein	=	Milk true protein %	%
24.13	=	Energetic value for protein	
Lactose	=	Milk lactose %	%
21.60	=	Energetic value for lactose	
Milk	=	Average milk produced	kg/cow/d
0.721	=	Energy value of 1 kg of standard milk (standard milk is defined for this program as 3.75% fat, 3.0% true protein and 4.9% lactose).	Mcal/kg

Project applicants must use dairy-specific values for fat, true protein, and lactose characteristics when available. If unavailable, the default values for standard milk may be used. The ECM is used to estimate energy-corrected milk production in metric tons over 10 years. Dividing the net GHG emission reduction over 10 years by this value yields the GHG reduction per unit energy-corrected milk produced metric.

The **'Co-Benefits'** tab also includes the estimation of several Key Variables:

- Fossil fuel use reductions onsite (gallons);
- Renewable fuel generation (gallons); and
- Renewable energy generation (kWh).

Equation 15: Fossil Fuel Use Reductions (onsite)

$$FRg = \left(\sum_f (QF_{f,\,project} - QF_{f,\,baseline}) \times EC_f \div EC_{diesel} \right) \text{ x } 10$$

Where,			Units
FR_g	=	Net reduction in onsite fossil-fuel use	gallons (diesel equivalent)
$QF_{f,\ project}$	=	Estimated annual quantity of fuel consumed for fuel type 'f' after implementation of DDRDP project	gallons/yr or scf/yr
$QF_{f,\ baseline}$	=	Estimated annual quantity of fuel consumed for fuel type 'f' after implementation of DDRDP project	MMBtu/yr or gallon/yr
EC_f	=	Energy content for fuel *f*	MMBtu/ gallon or MMBtu/scf
EC_d	=	Energy content of diesel fuel	MMBtu/ gallon
10	=	Minimum project life	years

Equation 16: Estimated renewable electricity generation associated with use of recovered biogas.

$$REG = (BE_{CH4} - PE_{CH4}) \div 25 \times 1000 \times AF \times EC_{CH4} \times NEE \times EEF \times 10$$

Where,			Units
REG	=	Estimated renewable electricity generation over project life	kWh
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e$/yr
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e$/yr
25	=	Global warming potential factor of methane. (Dividing by this value converts $mtCO_2e$ back to $mtCH_4$)	$mtCO_2e$/ $mtCH_4$
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
1000	=	Conversion from metric tons to kg	kg/mt
EC_{CH4}	=	Energy content of methane	$kWh/kgCH_4$
NEE	=	Net electrical conversion efficiency. This QM assumes a default value of 0.3 for IC engines and turbines, and 0.45 for fuel cells.	
10	=	Minimum project life	years

Equation 17: Estimated renewable fuel generation associated with use of recovered biogas as transportation fuel.

$$RFG = (RFG_{tr} + RFG_{NG}) \times 10$$

Where,

$$RFG_{tr} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times RF \times EC_{CH4} \div EC_{D}$$

And,

$$RFG_{NG} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times UF \times EC_{CH4} \div EC_{D}$$

Where,			Units
RFG	=	Estimated renewable fuel generation over 10 years	gallons diesel equivalent (DGE)
RFG_{tr}	=	Estimate renewable natural gas transportation fuel	DGE/yr
RFG_{NG}	=	Estimate renewable natural gas combusted in boiler that displaces fossil natural gas in industrial process	DGE/yr
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $mtCO_2e$ values calculated previously back to $mtCH_4$)	
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
RF	=	Recovery Factor of 0.9. Assumption that 90% of methane in biogas is ultimately recovered as biomethane.	
EC_{CH4}	=	Energy content of CH_4	MMbtu/mt CH_4
EC_D	=	Energy content of diesel fuel	MMBtu/ gallon
UF	=	Utilization factor. Fraction of thermal energy from boiler used in non-BCS processes that directly reduce fossil natural gas demand.	fraction (0-0.7)

Appendix C. Definitions of Manure Management System Components

Table C.1. Definitions of Manure Management System Components

System	Definition
Pasture/Range Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread Paddock	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Uncovered anaerobic lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
Anaerobic digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO2 and CH4, which is captured and flared or used as a fuel.
Burned for fuel	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Cattle and Swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.
Composting – In-vessel*	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
Composting – Static pile*	Composting in piles with forced aeration but no mixing.
Composting – Intensive windrow*	Composting in windrows with regular (at least daily) turning for mixing and aeration.
Composting – Passive windrow*	Composting in windrows with infrequent turning for mixing and aeration.
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.

*Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

Endnotes

[i] https://www.cdfa.ca.gov/oefi/ddrdp/.

[ii] As described in Volume 1 of the California Air Resources Board. Funding Guidelines for Agencies Administering California Climate Investments (December 21, 2015) (Funding Guidelines). www.arb.ca.gov/cci-fundingguidelines

[iii] California Air Resources Board. (2014). *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems*. https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.

[iv] California Air Resources Board. (2011). *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems*. https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.

[v] Greenhouse Gas Quantification Methodology for the California Department of Food and Agriculture Dairy Digester Research and Development Program Greenhouse Gas Reduction Fund Fiscal Year 2014-15. www.arb.ca.gov/cci-quantification.

[vi] California Air Resources Board (2017). California Climate Investments Quantification Methodology Emission Factor Database. Available at: www.arb.ca.gov/cci-quantification.

[vii] Previous versions are available on CARB's website at: www.arb.ca.gov/cci-quantification.

[viii] California Air Resources Board. DRAFT Funding Guidelines for Agencies Administering California Climate Investments. (August 4, 2017). www.arb.ca.gov/cci-fundingguidelines.

[ix] GWP values are taken from the Intergovernmental Panel on Climate Change Fourth Assessment Report (2007). https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html. Note that this is consistent with all other GGRF programs, but differs from the current use in the Livestock Protocol of 21 for the GWP of methane.

[x] California Climate Data Archive: http://www.calclim.dri.edu/pages/stationmap.html. Applicants should use county-specific defaults provided in the CARB QM Calculator Tool.

[xi] California Air Resources Board (2017). California Climate Investments Quantification Methodology Emission Factor Database. Available at: www.arb.ca.gov/cci-quantification.

[xii] California Air Resources Board. (2016). *Greenhouse Gas Quantification Methodology for the California Department of Resources Recycling and Recovery Waste Diversion Grant and Loan Program, Greenhouse Gas Reduction Fund Fiscal Year 2015-16*. www.arb.ca.gov/cci-quantification.

[xiii] UC Davis Biomass Collaborative, U.S. EPA Region 9, and National Risk Management Research Lab Office of Research and Development. (September 2016). p. 33-34. *Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies.* http://biomass.ucdavis.edu/wp-content/uploads/2016/11/EPA600R-16099_BiogasTech_Sept2016.pdf.

[xiv] UC Davis California Biomass Collaborative. (2016). *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California: FINAL TECHNICAL REPORT to the State of California Air Resources Board*. Stephen Kaffka, et al. http://biomass.ucdavis.edu/wp-content/uploads/2016/06/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf.

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